5.0 WATER BALANCE

This section in the Technical Assessment report brings together all the water related processes in WRIA 20 that have been addressed in previous sections of this report or in studies conducted by the Bureau of Reclamation. Information regarding precipitation, streamflow, water use and groundwater are brought together to further the understanding of how water is apportioned in the watershed and in individual sub-basins within the watershed. Given the size of the watershed, the generally low volume of water use and high proportion of forest evapotranspiration, a water balance approach was selected that assumes no net change in annual groundwater storage. Because the groundwater component of the water balance is anticipated to be small, errors associated with estimating larger components of the water balance (e.g., evapotranspiration and streamflow) do not justify the use of a watershed scale water balance to calculate available groundwater. Instead, groundwater availability and use are discussed separately in Section 2.

The hydrologic cycle forms the technical basis for watershed planning. The traditional method for characterizing the hydrologic cycle at a watershed scale is through a water balance. A physical water balance uses measured data or scientific methods to estimate current and future water use and availability. This section discusses the methodology used to create a physical water balance for WRIA 20, what the balance can illustrate data used and results, and the accuracy and sensitivity of this information.

5.1 Study Area

WRIA 20 has been divided, for purposes of the water balance, into seven primary sub-basins and five small sub-basins, shown in Figure 5-1. Of the seven larger sub-basins, the Sol Duc, Calawah, Bogachiel, and Dickey drain towards a single river - the Quillayute River, close to its mouth at the Pacific Ocean. Of the remaining three larger sub-basins only the Hoh and Ozette River drain primarily to a single outlet. The Sooes River, as well as the remaining grouped sub-basins (noted as Pacific 1 through 5), consist of many smaller drainages with rivers and creeks originating in the lowlands and draining directly into the Pacific.

Precipitation in the form of rain and snow is the primary source of water in WRIA 20 with the only other identified source being fog-drip (Harr, 1982). Much of the watershed is in lower elevation areas and receives precipitation in the form of rain with snow pack only existing for brief periods (generally several days). Portions of the Sol Duc, Bogachiel, and Hoh contain higher elevation areas where snow may exist over a period of weeks or months. Precipitation occurs year-round but the greatest precipitation generally occurs between November and January and the least precipitation occurs between June and August.

Water balances were completed for the Bogachiel, Calawah, Dickey, Hoh, Sol Duc, Ozette and Sooes sub-basins (Figure 5-1). Water balances were not performed for the five smaller sub-basins referred to as Pacific 1 through 5 because:

- Numerous smaller creeks draining sub-basins along the shore are not gauged;
- These areas are expected to act as natural systems due to their remote location and existence within National Park Boundaries;
- Water use was not calculated for Pacific sub-basins 1 through 5 and is not expected to be significant now, or in the future; and

- Streamflow estimates provided by the Bureau of Reclamation (BOR) did not include Pacific sub-basins 1 through 5.

5.2 Previous Studies

Several studies specific to the watershed were used to provide background, data or methods in the water balance. These include:

- *Watershed Analysis Studies completed for the Sol Duc, East and West Dickey and North Fork and South Fork Calawah sub-basins (USDA Forest Service 1995, Rayonier, 1998, USDA Forest Service 1996, and USDA Forest Service 1998).*

These reports were completed by varying groups of private/public partnerships and are intended to serve as the basis for forest practice prescriptions on State and private lands, and as guidance for site specific activities and long range land management planning on federal lands. Most of the analyses were completed using the Standard Methodology for Conducting Watershed Analysis Manual, Version 4.0 (Washington Forest Practices Board, November 1997), as well as the Ecosystems Analysis at the Watershed Scale: Federal Guide for Watershed Analysis [the Federal Guide; USDA Forest Service and U.S. Department of the Interior (USDI) Bureau of Land Management, 1994]. Hydrologic analysis conducted under these studies generally evaluated whether forest practices impacted peak flow through modification of rain-on-snow and spring snow melt processes.

- *Overview of Watershed Conditions and Seasonal Variability in Streamflow for Select Streams within WRIA 20, Olympic Peninsula, Washington (BOR, in Draft).*

The Bureau of Reclamation report provides a "comprehensive appraisal level overview of watershed conditions within WRIA 20". The BOR uses a method termed the watershed characteristics method to calculate the range of flow variability and monthly discharge for natural, undisturbed watershed conditions at ungaged locations along each selected stream. This method involves the transference of of flow characteristics from gaged watersheds to ungaged watersheds. An appendix (this report is still in draft) describing the application of this method to WRIA 20 will be included in the final report. In addition, these reports include a discussion of watershed responses to changes in watershed conditions.

- *U.S. Geological Survey, Low-Flow Characteristics of Streams on the Olympic Peninsula, Washington. Open-File Report 77-812.*

This report provides estimates of the magnitude, frequency, and normal period of occurrence of low flows on certain streams on the Olympic Peninsula based on measured data.

5.3 Background Issues

5.3.1 Streamflow Estimates

Naturalized monthly average streamflow estimates, developed by the Bureau of Reclamation (BOR), were used to calculate the streamflow (referred to as runoff) component of this water balance. It is assumed, based on conversations with BOR, that their streamflow estimates represent flows that would occur if no water was withdrawn from the system. These BOR synthesized flows are not adjusted for vegetation maturity. The streamflow (runoff) component of this water balance was calculated using the BOR streamflow estimates and subtracting actual residential and irrigation water use (both surface and groundwater use) from them (see Section 4, Water Use). This document does not include an analysis of the BOR methodology or a comparison of their results with measured data. The methodology used by the BOR to develop streamflow estimates is included in Appendix B.

5.3.2 Fog Drip

Fog-drip is water that drips to the ground from trees or other objects that have collected moisture from drifting fog. Some studies have estimated fog-drip to account for as much as 20-50% of total water input to the basin (Harr, 1982; Dawson, unpublished). Water input from fog drip is not quantitatively addressed in this water balance. Fog drip data are not captured by standard climate station measurements and well accepted methods do not exist to estimate fog drip.

5.4 Hydrologic Cycle

The hydrologic cycle forms the technical basis for water resource decision making at multiple scales. At a global scale, the hydrologic cycle describes the circulation of water between the oceans, atmosphere and land. At the watershed scale, the hydrologic cycle focuses on the land-based hydrologic system that is bounded by surface water divides.

A watershed must be viewed as a combination of both the surface drainage area and the subsurface materials that underlie the watershed. A clear understanding of the hydrologic cycle at the watershed scale involves an inventory of the water inputs, outputs and storage within the watershed. Knowledge of the dynamic processes that occur within a watershed hydrologic cycle provides an understanding of what effects various resource management approaches will have on the natural system.

The hydrologic cycle, illustrated in Figure 5-2, is a network of inflows and outflows that may be expressed as a water balance or water budget by equating the primary variables (input, output and change in storage):

$$\text{Input} = \text{Output} + /\text{-}\ \text{Change In Storage}$$

This equation is a conservative statement that ensures that all the water within the watershed is accounted for and that water cannot be lost or gained.

The main input to the hydrologic system is precipitation falling as rain or snow. The amount of precipitation is the primary control on the amount of water that may be available within the watershed. Additional inputs to the hydrologic system may include fog-drip captured in vegetation and groundwater inflow from adjacent watersheds.

Outflow from a watershed occurs naturally as streamflow or runoff, groundwater discharge, and as evapotranspiration. Evapotranspiration is the combination of evaporation from open bodies of water, vegetation and soil surfaces, and transpiration from vegetation. Outflow from a watershed also occurs as a result of human consumption and redirection of flows.

Movement of water within a watershed occurs naturally through a number of processes. Overland flow delivers precipitation to stream channels. Infiltration results in movement of water at the land surface downward into the subsurface. Groundwater flow results in movement of water within the subsurface either to streams (baseflow) or other outlets. The nature of the land surface and subsurface controls run-off, infiltration rates and groundwater flow rates. Infiltration rates and groundwater flow rates in turn influence the timing and spatial distribution of surface water flows. Groundwater flows and surface water flows are linked by the relationships between infiltration, groundwater recharge, baseflow and streamflow generation.

Movement of water within a watershed is also impacted by a number of anthropogenic factors including groundwater pumping, extraction of surface water, stormwater generation and discharge, wastewater generation and discharge, and agricultural, land use and forest management practices, as well as by climate variability and climate change. These factors are discussed below.

5.4.1 Anthropogenic Changes

Anthropogenic changes associated with increasing population and population densities can have varied impacts on water resources. Water use includes elements such as water withdrawal from surface- and ground-water sources, water delivery to homes and businesses, consumptive use of water, water released from wastewater-treatment plants, water returned to the environment, and instream uses, such as using water to produce hydroelectric power.

Water use for domestic purposes can change the timing and location of water delivery in the hydrologic cycle. For example water that would normally be under ground may be pumped to the surface and applied to the ground to water lawns. Additionally, water use is typically at its peak when water availability is lowest. Urbanization is accompanied by accelerated drainage of water through road drains and city sewer systems, which can increase the magnitude of urban flood events. Urbanization can also alter the rates of infiltration, evaporation, and transpiration that would otherwise occur in a natural setting.

5.4.2 Climate Variability and Climate Change

Information on climate variability and climate change is the focus of studies by the University of Washington Climate Impacts Group (UW CIG, 2004). The following information is excerpted from a memo distributed by that group dated April 15, 2004.

The El Niño/Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) are important sources of natural climate variability affecting the Pacific Northwest. ENSO and PDO are natural cycles in Pacific Ocean sea surface temperatures and related ocean/atmosphere dynamics that influence climate globally. ENSO phases, also known as El Niño (the warm phase of ENSO) and La Niña (the cool phase of ENSO), are a major source of year-to-year climate variability, typically lasting 6 to 18 months and reaching peak intensity in December. The PDO, which is also categorized as warm phase or cool phase, is a major source of decadal-scale (approximately 10 to 30 years) climate variability. Figure 5-3 shows the general trends of the PDO cycle between 1900 and 2003.

The changes in regional temperature and precipitation associated with warm and cool ENSO/PDO phases affect many aspects of the Pacific Northwest environment (Table 5-1). For example, the warmer and drier conditions that typically occur with warm phase ENSO and PDO increase the potential for reduced snowpack, lower streamflows, degraded coastal and near-shore ocean habitat quality, reduced salmon runs, drought and forest fires. Cool phase ENSO and PDO conditions increase the potential for the opposite effects. The 20th century ENSO/PDO phases are listed by year in Table 5-2.

In addition to the interannual effects of natural climate variability, water resources in WRIA 20 will also be affected by global climate change. An evaluation of seven 21st century climate change scenarios for the Pacific Northwest shows that, in general, the region is expected to get warmer and wetter as a result of climate change. These climate change scenarios are based on assumptions about (1) future greenhouse gas and aerosol emissions, and (2) modeled sensitivity to those changes. Both are imperfectly known but the scenarios produced provide valuable insights into likely future conditions.

Based on the evaluation of seven global warming scenarios, the CIG projects increases in average annual temperature on the order of 2.5°F by the 2020s and 3.8°F by the 2040s (Table 5-3). Pacific Northwest winters are also projected to get wetter on average (+8%), but the range of uncertainty in precipitation change is much larger than that associated with temperature change. Projected increases in summer precipitation are negligible given how little rain falls in the summer and may be lost if evapotranspiration rates increase. All of these changes are expected on top of the 1.5°F warming (average) already experienced throughout the region during the 20th century.

Streamflows in low elevation "rain dominant" basins respond directly to precipitation events and generally peak in mid-winter with the Pacific Northwest wet season. Climate change impacts in rain dominant basins, therefore, depend primarily on projected changes in winter (October-March) precipitation, which are less certain than projected temperature changes.

If total winter precipitation increases as projected and/or precipitation intensity in individual storms increases, annual flow volumes in rain dominant basins should increase. The severity of floods and flood-related impacts, including erosion, infrastructure damage, and loss of salmon nests ("redds") to high flow riverbed scouring events, may also increase. The opposite effects would be experienced if total precipitation in winter decreases and/or the precipitation intensity in individual storms decreases. On the positive side, increases in spring precipitation could increase summer water availability if storage is available. Changes in the seasonality of streamflow are expected to be minimal in rain dominant basins unless the seasonality of precipitation is significantly altered by climate change.

Although most of WRIA 20 can be considered to be a "rain dominated" basin, portions of the Sol Duc and Hoh sub-basins can be considered "transient snow" basins. Transient snow basins are located near the current mid-winter snowline and as such, receive a mix of winter precipitation dependent on elevation. Lower portions of the basin will receive rain throughout the winter season. Mid-elevation portions of the basin will receive rain in autumn and early winter with a transition to snow in late winter. The highest elevations of the basin may accumulate snow throughout the winter season. Because of these characteristics, hydrographs for transient basins are noted by two seasonal runoff peaks: the first runoff peak occurs in mid-winter with the peak in fall rains (November-January) while the second runoff peak occurs during the period of spring snowmelt (May-June).

Of the three hydrologic basin types (rain dominant, transient snow, and snowmelt dominant), transient basins are the most sensitive to climate change because average winter (October-March) temperature in large portions of these basins is near the freezing threshold. A few degrees of warming in transient basins is enough to shift temperatures above freezing for longer periods over more of the basin, resulting in more winter precipitation falling as rain rather than snow and reducing the amount of water stored as snow in mid-winter. This combination of effects also results in higher winter flows and increased risk of winter flooding.

Climate change impacts on winter precipitation and snowpack accumulation have important carry-over effects on the volume and timing of spring and summer streamflow. Temperature-induced reductions in winter snowpack reduce the volume of spring and summer streamflow in transient basins. In a simulation of climate change impacts on a west Cascades transient basin, for example, a 4.5° F warming scenario resulted in a 35% reduction in April-September inflows.

Changes in the timing of spring streamflow are driven by the influence of warmer winter/spring temperatures on the timing of snow melt. Warmer temperatures earlier in the snowmelt season induce earlier snow melt, potentially shifting the peak of spring runoff earlier into the spring season by as much as four weeks by 2040. This shift in streamflow timing may affect a transient basin's ability to meet water demands during the driest time of the year by lengthening the time between peak spring runoff and the onset of fall rains.

For both rain dominant and transient snow basins, warmer summer temperatures may reduce late summer base flows if net evapotranspiration increases. Changes in cloud cover and wind (which are difficult to model reliably) can have significant mitigating effects on evapotranspiration losses, however. Decreased base flows in late summer and higher water temperatures may pose threats to cold water fish, including salmon. On the demand side, warmer summer temperatures are projected to increase summer water demand.

5.4.3 Forest Management

In forest ecosystems, the underlying processes that control water movement are: evaporation, transpiration, snow pack energy balance, infiltration, percolation, and lateral subsurface flow (Waring and Schlesinger, 1985). Most of these processes are not easily quantified through direct measurement. Estimation of these processes requires measurement of parameters such as seasonal canopy leaf area, wind, humidity, solar radiation, canopy height and soil hydrologic characteristics, parameters that are not readily available and vary widely spatially. Computer simulation models can often be the most effective method for predicting the interaction of these parameters in a forest ecosystem as well as their relative importance.

As a result of the complexity of the forest hydrologic cycle and process understanding, determining the overall response of a watershed to forest management practices is difficult. There have been few well-controlled paired-watershed experiments and, of those, the variability of climate and lithologies among studies results in inconsistent and unsupported findings that may not be applicable to varied areas. However, there are several hydrologic responses to forest management practices that are well accepted. Table 5-4 summarizes generally accepted hydrologic responses to deforestation. In general, the opposite response would be expected from afforestation. The magnitude of the components response as well as the length of time the response can be observed can be expected to vary from basin to basin depending on basin characteristics and magnitude of forest change. A further discussion o fthe effects of land use on water resources, and specifically for forest lands, can be found in Section 6.3.2.

5.5 Water Balance Objective and Level of Detail

The watershed planning process is designed to bring stakeholders together as a group to determine the future of water management in their basin. The water balance is an important part of this process because it represents the integration of each watershed study component. Therefore, the objective of this water balance is to provide a tool that can easily be understood and utilized by a diverse group of people for assessing allocation of water within WRIA 20 sub-basins.

The level of detail for this study is a monthly and annual water balance at the sub-basin scale. The seven sub-basins used in the analysis are described in Table 5-5 and shown in Figure 5-1. The water balance was created using a spreadsheet that clearly displays each component and its relative influence on the water balance. Several issues should be noted when applying this water balance for purposes of watershed planning.

- The relative magnitudes of each hydrologic parameter are aggregated at a sub-basin geographic scale and a monthly time scale. This format can be easily implemented in a spreadsheet, but lacks the fine scale necessary for site-specific studies. Therefore, it provides a basis for management strategies that will affect hydrologic features at a comparable scale.
- The water balance provides a basic assessment of groundwater/surface water interaction at a sub-basin scale. Most hydrologic parameters in a water balance are directly measured (precipitation, water use, etc.), while others, such as groundwater recharge or discharge, are calculated as a "residual" in the water balance equation.
- The water balance provides only a very basic assessment of water availability for habitat needs. Habitat management issues may require additional "fine scale" assessment (both spatially and temporally) to quantify water availability for habitat purposes.

5.6 Water Balance Approach

Watershed water balance refers to the balance between the inflow of water to a watershed as precipitation, any changes in storage, and the outflow of water from the watershed as evapotranspiration, ground water discharge, and streamflow. Basically, a watershed water balance is an accounting tool to keep track of the inputs and outputs of the hydrologic cycle in a watershed over time.

The units used in a water balance are, by convention, inches and acre-feet. Values expressed in inches are typically used to compare the relative magnitude of the components of the water balance within a sub-basin. Values expressed in acre-feet are typically used to compare the relative magnitude of the components of the water balance between sub-basins. This is an important distinction. An inch of water in a large sub-basin represents more water than an inch of water in a small sub-basin. The water balance is analyzed over the water year, defined as the October 1 through September 30 (i.e. the beginning of autumn through to the end of summer).

The following components are incorporated for each sub-basin water balance on both a monthly and annual time step. Sources of data used for each component are discussed in the subsequent section (Section 5.7 Water Balance Data Sources).

1. *Precipitation*: Total monthly precipitation that falls as rain or snow within the sub-basin.
2. *Snow accumulated*: The proportion of precipitation that accumulates as snowpack reported as a cumulative amount of snow water equivalent.
3. *Rainfall + Melt*: The amount of water released from snowpack plus the amount of precipitation falling as rain. Water released from snowpack is calculated using a simple temperature model based on degree-day melting rate.
4. *Observed Run-off*: Mean monthly run-off (streamflow) developed by the BOR and corrected by subtracting water use estimates for that sub-basin from the BOR estimates.
5. *Irrigated Net Use*: Agricultural irrigation is considered a minor water use component within WRIA 20. It is assumed that all irrigated water use is consumptive.
6. *Residential Net Use*: Residential use is incorporated through monthly water use data obtained from the City of Forks and applied to the entire population of the WRIA (through either municipal water systems or exempt wells). It is assumed that all residential use is consumptive use.
7. *Predicted Run-off*: Rainfall + Melt minus water use + actual evapotranspiration estimates in the basin.

8. *Net Residual*: This component can represent several processes including sub-surface flow (groundwater and irrigation return flows), sublimation from snowpack, water storage in the unsaturated zone and evaporation from water surfaces. For this model net residual is only relevant on a monthly scale because on an annual basis it is assumed that the net residual is zero. This means that its assumed no inter-annual storage exists in snow or glaciers, soil moisture, canopy storage, etc.

5.6.1 Annual Water Balance

The general approach for the annual water balance on a sub-basin basis is:

$$P = RO + CU + NR + \Delta S \qquad [1]$$

Where

P = Precipitation, an externally modeled component, based on measured data.
RO = Runoff, derived data developed by the BOR.
CU = Consumptive use, a calculated component, based on measured data.
NR = Net residual can be calculated or estimated, the annual net residual is assumed to be zero in this approach.
ΔS = Change in storage, measured variable, currently managed inter-annual storage does not exist in WRIA 20.

All units are in inches. The annual water balance is applied for a water year, beginning in October and ending in September.

5.6.2 Monthly Water Balance

Snow accumulation and melt must be addressed in a monthly water balance because precipitation falling as snow in one month may not be released as snowmelt until several months later. The general monthly water balance equation is as follows:

$$R + M = RO + CU + NR + \Delta S \qquad [2]$$

Where:

R = Rainfall, an externally modeled component, based on measured data.
M = Snowmelt, a calculated component.

All units are in inches. Note that by the end of the water year, cumulative rainfall plus melt is equal to total precipitation, assuming sublimation from snow is negligible. Thus, the monthly and annual water balance approaches are compatible.

The methods used to estimate all components in the water balance are described below.

5.6.3 Rainfall and Snow Accumulation/Melt

Snow accumulation (A) and melt (M) can be estimated on the basis of mean monthly precipitation and temperature. When mean monthly temperature (T) is below a base temperature, a fraction of the monthly precipitation (P) is added to the snowpack. The remaining fraction of the precipitation is added to rainfall (R):

For $T \le T_b$:

$$A = P * P_x \quad [3a]$$
$$R = P * (100\%-P_x) \quad [4a]$$
$$M = 0 \quad [5a]$$

Where:
T_b is the base temperature, set to 2°C for this study.
P_x is the fraction of precipitation, which becomes snow, set to 85% for this study.
A, R, and M are in units of inches in the above equations.

By using $P_x < 100\%$, the model allows for rainfall and snow accumulation to occur in the same month (rain on snow).

When temperature exceeds the base temperature, all precipitation is added as rainfall and the snowpack is melted according to the degree-day approach:

For $T > T_b$

$$A = 0 \quad [3b]$$
$$R = P \quad [4b]$$
$$M = C_x * (T-T_b) \quad [5b]$$

Where:
C_x is a degree-day factor in units of inches/(^{0}C·day), set to 0.97 in this study.

5.7 Water Balance Data Sources

The data used to complete the water balance were obtained from a variety of sources. Each data source and its use in the water balance are discussed below.

5.7.1 Precipitation

Monthly gridded precipitation data were obtained through the Oregon Climate Surface PRISM modeled results. The Parameter-elevation Regressions on Independent Slopes Model (PRISM) provides an integrated basin-scale analysis of climate. PRISM is a model developed by Oregon State University that uses measured point data and digital elevation model (DEM) data to generate grid-based estimates of climate parameters (Daly et al., 1994). Unlike other statistical methods used today, PRISM was written by a meteorologist specifically to address climate variability. PRISM is well suited to mountainous regions because the effects of terrain on climate play a central role in the model's conceptual framework. Data input to the model consisted of 1961-1990 mean monthly precipitation from over 8,000 National Oceanic and Atmospheric Administration (NOAA) Cooperative sites, Snowpack Telemetry (SNOTEL) sites, and selected state network stations. PRISM is used to estimate mean annual, mean monthly and event-based precipitation, temperature, and other variables. The model grid resolution is 4-km (latitude and longitude). The outputs used in this study are re-sampled to 2-km resolution using mathematical filtering procedures (Daly et al., 1994). Figure 5-4 presents average annual precipitation data obtained from PRISM model output.

The Washington Forest Practices Board Watershed Analysis Manual defines five distinct precipitation zones on the basis of elevation. These five zones, delineated by elevation, include: lowland (<800 feet), rain dominated (800-1,700 feet), rain on snow (1,700-3,000 feet), snow dominated (3,000-4,500 feet) and highland (>4,500 feet). For the purposes of this study, the lowland zone has been included with the rain dominated zone and the highland zone has been grouped with the snow dominated zone. Figure 5-5 shows the distribution of the three major precipitation zones within WRIA 20. Table 5-6 presents PRISM average monthly precipitation by precipitation zone and sub-basin for each of the seven major sub-basins.

The NOAA and National Weather Service (NWS) co-operative (NOAA/NWS COOP) maintain several continuous climate stations within the basin. The locations of these stations are shown in Figure 5-6. For purposes of the water balance, point measurements of climate variables are of limited use because these variables vary widely over a sub-basin. Therefore, these point measurements within the watershed were used to check the accuracy of PRISM modeled annual precipitation. A summary of existing stations and a comparison, where possible, of those gages with PRISM annual precipitation at that point is shown in Table 5-7. Based on average annual precipitation data from climate stations within the watershed the PRISM modeled precipitation results appear to adequately represent precipitation in the basin.

5.7.2 Streamflow

As described in Section 5.3.1, this water balance uses naturalized monthly average streamflow estimates, developed by BOR, to estimate runoff. Table 5-8a presents the monthly average flows used in this water balance. In order to present water balance results on a sub-basin scale, streamflow for a single sub-basin cannot include flows from tributaries that are also defined as major sub-basins (sub-basins are outlined in Figure 5-1). Therefore, flow presented for this analysis in the Bogachiel River sub-basin does not include Calawah River inflow and flow presented for the Sol Duc River sub-basin does not include inflow from the Bogachiel, Dickey and Calawah sub-basins. These altered monthly values, utilized in the water balance calculations (in units of inches), are presented in Table 5-8b.

The BOR also produced 10%, 51% and 89% exceedance probability results for sub-basin outlets. Exceedance probability plots are used to understand how often, or how probable it is that a certain flow will be equaled or exceeded in a specified time frame. Exceedance probabilities are also called recurrence intervals, or, more generally, frequency analysis. Frequency analysis techniques were primarily developed by civil engineers, who needed to determine design criteria for hydrologic structures, particularly during hydrologic extremes (e.g. floods and droughts). The data used in these types of analyses are purely historical and the “reliability” of frequency analysis increases with the length of the historical period of record. The occurrence of a certain exceedance probability flow in one month does not mean that the same exceedance probability will occur in the next month. Therefore, frequency analysis is useful in setting design criteria, but less useful for deciding how to respond to observed conditions. Figures 5-7a through 5-7h present the 10%, 51% and 89% exceedance curves at the outlets of each of the major sub-basins using BOR produced streamflow data. Appendix B presents the methodology used by the BOR to estimate these exceedance values. Mean annual flows as estimated by the BoR in WRIA 20 sub-basins ranges from 264 cfs in the Sooes River to 4638 cfs in the Sol Duc River.

5.7.3 Temperature

As with precipitation, monthly temperature data were obtained through Oregon Climate Surface PRISM model results. PRISM is described in Section 5.7.1. Table 5-9 presents PRISM annual and monthly temperature for each sub-basin and precipitation zone. Mean annual temperature in WRIA 30 sub-basins is estimated to range from 8.2 °C in the Hoh to 9.9 °C in the Dickey.

5.7.4 Water Use

Water use information was obtained through a number of sources, each of which is discussed in detail in Section 4. Tables 5-10 a-c summarize current annual and monthly domestic, agricultural and total water use by sub-basin. Note that the industrial/commercial water use is not included in this analysis.

Monthly domestic water use is presented in Table 5-10a and was obtained using the monthly per capita water use factors presented in Table 4-3 and 2000 U.S. Census data presented in Table 4-2a for each sub-basin. These per capita water use factors are assumed to apply over the entire watershed and to both residential use from municipal systems and exempt well use. The Quileute Tribe's monthly water use data are included as part of domestic water use in the Sol Duc sub-basin. Quileute annual and monthly water use is summarized in Table 4-5. Total annual domestic water use ranges from 8.9 AF/month in the Sooes to 509.9 AF/month in the Calawah.

Monthly agricultural (irrigation) water use was calculated using the annual values presented in Table 4-4. Section 4 describes the data sources and methods used to obtain these annual values. In determining monthly agricultural water use, it was assumed that water use relating to agricultural purposes typically occurs during the growing season, from April 15 through October 15. The total annual agricultural water use values presented in Table 4-4 were evenly distributed over the growing season to obtain monthly agricultural water use values for each sub-basin, which are presented in Table 5-10b. It was assumed that water use for stock is negligible on a watershed scale in WRIA 20. Total annual agricultural water use is estimated to range from 10.1 AF/month in the Sooes to 637.8 AF/month in the Calawah.

5.7.5 Evapotranspiration

Evapotranspiration includes water that evaporates from the soil and plant surfaces as well as water transpired by plants. At a small scale, estimates of evapotranspiration take into account vegetation type, maturity, the way wind moves through a canopy, and stomatal conductance, among other factors. However, it is not practical to perform such a detailed characterization of evapotranspiration at a watershed scale. For purposes of a watershed-wide water balance, techniques that apply at a watershed scale, rather than a laboratory or small experimental forest scale are appropriate.

Evapotranspiration is often described using two terms: potential evapotranspiration and actual evapotranspiration. Potential evapotranspiration or PET is a measure of the ability of the atmosphere to remove water from a surface through the processes of evaporation and transpiration assuming no control on water supply. Actual evapotranspiration or AET is the quantity of water that is actually removed from a surface due to the processes of evaporation and transpiration.

In the WRIA 20 water balance, annual actual evapotranspiration (AET) is estimated as the difference between precipitation and runoff (streamflow) at the multi-year timescale. Therefore, for the purposes of this water balance, the evapotranspiration component represents water transpired by plants, from soil, and plant surfaces, and also from open water (such as lakes). This method assumes there is no net change in groundwater, soil, snow, or canopy storage on an annual basis. Annual AET was calculated using average annual streamflow from the BOR (less water use estimates) and average annual precipitation output from PRISM for each sub-basin.

In order to distribute AET annual data to a monthly time step for the water balance, the temperature based Blaney-Criddle method (Dunne and Leopold, 1978) was used. The Blaney-Criddle method calculates potential evapotranspiration (PET) using longitude and latitude, average air temperature, the monthly fraction of annual day light hours and an empirical crop coefficient. Table 5-11 summarizes monthly and annual AET values for each sub-basin.

The Blaney-Criddle formula is:

$$PET = (0.142Ta + 1.095)\ (Ta+17.8)kd$$

Where:
PET = Potential Evapotranspiration (cm/mo)
Ta = average air temperature (C) when Ta is less than 3°C the first term is set to 1.38
k = empirical crop factor that represents the crop type and stage of growth (taken from a reference table) d = the monthly fraction of annual hours of daylight (reference table available based on latitude)

The crop factor is generally taken from a reference table, and is usually more applicable to farmed crops than to forests. In this case the Blaney-Criddle formula for PET is being used solely to determine the portion of annual evapotranspiration (ET) that occurs in any one month. Therefore a crop coefficient for the land cover of WRIA 20 is not used.

Total annual ET in WRIA 20 is estimated to range from 11.40 inches in the Calawah sub-basin to the 48.48 inches in the Ozette sub-basin. The Sooes and Ozette sub-basin are estimated to have significantly higher (approximately 12 to 23 inches higher, respectively, than any other sub-basin) total evapotranspiration than other sub-basins in WRIA 20. The higher total ET in the Ozette sub-basin can be explained by the presence of Lake Ozette, a large body of water, that would contribute high rates of evaporation. The high total ET in Soess is less understood. It may be due to climatic conditions that occur in the lowland, sub-basins, in northern WRIA 20 especially. Assessment of measured rainfall from Neah Bay and measured Sooes River flows corroborates the presence of a potentially higher total annaul ET.

There are many methods available for calculating AET and, as was mentioned previously, most of these either require parameters that are not readily available or use empirical equations developed for crops. Because the method chosen for this water balance utilizes other parameters that are also part of the water balance, it inherently will result in a "balanced" water balance on an annual timescale. Therefore, it is logical to explore what range of AET may exist if it is calculated independently of other water balance parameters. Table 5-12 compares three methods for estimating actual evapotranspiration in WRIA 20 with water balance AET values. Annual AET estimates from these three methods range from 20.9 to 26.8 inches, which is a relatively narrow range. Waring and Schlesinger (1985) report that, under ideal conditions, 6mm/day is the maximum evapotranspiration that could be seen from a forest on any one day. If this amount of ET were to occur year round, it would result in 86 inches of water lost to evapotranspiration. This could be considered a possible upper bound, but would only occur under ideal climatic conditions and ample water availability. In the Watershed Analyses completed within the WRIA per the Washington Forest Practices Board Watershed Analysis Manual, annual evapotranspiration was set to 20 inches for hydrologic analysis; this value is also within the range of calculated values used for this water balance.

5.8 Summary of Results

The results of the annual water balance for each sub-basin and WRIA 20 as a whole, excluding the small "Pacific" sub-basins, is shown in Table 5-13 and illustrated in Figures 5-8 and 5-9. Total volumes for the WRIA are displayed in both acre feet and cfs units in Table 5-13. This table also reports the partitioning of water as a percentage of total annual precipitation that falls in the basin. Figure 5-8 presents the annual water balance by sub-basin for WRIA 20. This figure illustrates that between 55% and 91% of water in each sub-basin runs off as streamflow, and that between 9.3% and 45% of water leaves the watershed as evapotranspiration. The quantity of water for human use, and the amount of water allocated through permits, certificates and claims are also shown.

In general the results show that there is not a significant amount of water use in the basin, and that the majority of precipitation that falls in the basin flows out of the basin as streamflow. Figure 5-9 shows that for the watershed (excluding Pacific basins and Ozette and Sooes) the majority of precipitation that falls in the basin, approximately 83%, leaves the basin as streamflow. The next largest parameter in the annual water balance is evapotranspiration at approximately 17%. Water use for both irrigation and domestic purposes are less than 0.03% of total inputs. The method used for calculating evapotranspiration assumes there are no inter-annual storage changes therefore groundwater and surface water storage do not factor into the annual water balance.

Results of the monthly water balance are displayed in Tables 5-14 through 5-20 for each sub-basin, respectively. All numbers are reported in inches of water, for intra-basin comparison.

Results of the monthly water balance show a pattern similar to that of the annual balance; the majority of precipitation runs off, with evapotranspiration from non-irrigated lands accounting for the next largest component. Water use for human needs makes up a very small portion of the total. Additionally, snow accumulation and melt is estimated to be a minor factor in the seasonal availability of water for streamflow, only the Hoh and Sol Duc have any significant snow accumulation. The seasonal nature of streamflow in all sub-basins mimics that of precipitation because there is not significant inter-monthly storage, such as snow. Figure 5-10 shows the water balance for the entire WRIA and for the Calawah sub-basin during the dryer summer months of July, August and September. The relative proportion of water leaving the watershed as ET increases significantly during the summer months, while the percentage as streamflow decreases. Figure 5-11 illustrates the actual water volumes of each component for each sub-basin estimated to occur during summer months.

The net residual in Tables 5-14 through 5-20 indicates water that is unaccounted for on a monthly time scale. Generally, this value is used to indicate groundwater interactions with surface water within a sub-basin. When negative, the net residual represents water that would be available to recharge groundwater; when positive it represents groundwater discharge to streams. In general, recharge occurs from fall to early spring, with discharge to streams occurring in the summer

5.9 Discussion of Results

The Hoh and Sol Duc both show brief periods in the late winter when groundwater discharge to streams is calculated to occur (net residual is positive). This is either due to variations in methods used by the BOR and Golder to estimate run-off, or it represents some temporary storage in the system that is not captured explicitly in the water balance. The BOR streamflow appears to show a higher winter peak and faster descending limb that that modeled by Golder, which results in a positive net residual during the late winter.

Long term variations in temperature from global warming should be considered in watershed planning discussions. Under several global warming scenarios, average annual temperature has been projected to increase by about 2.5°F in the next 15 years, and 3.8°F in the next 35 years. Increased precipitation may occur as a result of global warming, however there is too much uncertainty to determine the effects of this at this time.

In areas where heavy fog is common, large trees can capture the moisture in the fog. This moisture is reported to be both evapotranspirated by trees and condensed and dripped off the trees. Fog-drip has been found to be an important contributor to total effective precipitation in the redwood forest zone of the northern California Coast range and in one location in the Oregon Cascades (Dawson, unpublished). In the Bull Run watershed, Oregon Cascades, Harr (1982) estimated fog drip could increase water input by 20 inches, or 25 percent, relative to about 80 inches of rain measured in clearcuts. Fog does occur on the peninsula. Mean data for heavy fog visibility from the Quillayute Airport show that heavy fog (visibility of ¼ mile or less) occurred on average between 2.3 and 7.0 days per month, with 53 days per year of heavy fog on average (based on 28 years of record) and that the late summer and early fall experience the greatest number of days of heavy fog. Therefore, fog-drip could be a significant input to the watershed that is not captured in this water balance.